

Comparison of US and European Codes and Regulations for the Construction of LWR Pressure Components

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Abstract

The US and European codes and regulations actually applied in the design, construction, operation and inspection of pressure components in light water reactors are compared in a study undertaken by the German Technical Supervisor Association TÜV-Rheinland on request of the Commission of the European Communities.

The study was intended as a contribution to a stepwise harmonization of European Regulations.

The same safety related principles are applied in Europe and in US to assure the quality of all primary system components. Divergencies exist primarily in the organisation of quality assurance.

US and European codes and regulations admit only approved materials for the fabrication of pressure components. The German and French requirements ask, however, more restrictive limits as far as trace elements are concerned which, during operation, may contribute to the embrittlement of the material.

A further difference results from the considerably larger scope of materials examinations in European countries. A comparative list of the numbers of test specimens required under the different codes was prepared.

Also for the hydrostatic test, the most important acceptance test, differences were found. In European countries the test pressure for primary system components vary from 1.1 to 2.0 times the design pressure, while in the US the test pressure of the components is dependent on the design pressure of the entire system, 1.25 times design pressure.

1. Introduction

Codes and regulations actually applied in the design, construction, operation and inspection of nuclear heavy components in light water reactors are both, in the US and in Europe, based on the early regulations for the construction of industrial vessels and steam boilers; they were gradually improved with technical development and results of studies and, progressively, tests are incorporated in the existing codes. Notwithstanding the development along the same lines, important divergencies exist as shown in the study / 4 / undertaken on request of the Commission of the European Communities by the German Technical Supervisor Association TÜV-Rheinland.

The study was intended as a contribution to a stepwise harmonization of European Regulations. As an enlargement to the above study some of the reasons for existing divergencies were evolved in cooperation with representatives of the ASME Committee.

In most European countries the design of nuclear heavy components is based on the ASME Code Section III / 1 /, important divergencies were however found in the comparison of the ASME Code with German / 2 / and French / 3 / regulations in particular in the following main areas:

- quality assurance and fabrication prerequisites
- manufacturing and acceptance tests including material tests
- tests following pressure testing and
- non-destructive examination.

This contribution can, however, only specify some particular examples in above areas, which are of utmost importance to reactor safety.

2. Quality Assurance and fabrication prerequisites

A series of related and compatible criteria, standards and non-mandatory guidance for Quality Assurance exists at present, both nationally and internationally. Most member countries of the European Communities have their own Q.A. standards and two international Q.A. documents exist, one produced by the International Atomic Energy Agency (IAEA) and the other by the International Standards Organization (ISO).

All these standards are based on the same safety related principles to assure the quality of all primary system components as e.g.:

- the preparation of a safety evaluation report
- examination of design data
- consideration of certain safety factors in the design
- use of approved materials, and
- plant related recurrent testing.

Divergencies exist primarily in the organization of the Q.A. procedures.

In most European countries a design verification is performed on primary pressure components, either by an independent organization or by the Q.A. department of the manufacturer (persons not involved in the design process), before the component is manufactured.

Such a design verification is not performed in the US. Only the manufacturing facilities are checked by ASME and certificates issued.

Under the American system, in contrary to European practice, a manufacturer is entitled to manufacture or install pressurized parts for nuclear power plants if he is accredited as a N, NPT or NA Certificate Holder. Accreditation is the responsibility of the Nuclear Accreditation Committee, a subcommittee of the ASME Committee. The duration of validity of the accreditation depends on the audits carried out at regular intervals. In European countries, however, more emphasis is placed on the inspection of the manufactured component than on the verification of the manufacturer's capabilities.

In the ASME Code no specific tests are required, (e.g. process tests) to be carried out by an independent organization. The only requirement is that results of such tests and the relevant certificates are available and are presented to the Authorized Inspector on request. For granting accreditation as a Certificate Holder, it is mainly the experience of the manufacturing plant that is taken into account.

3. Material tests

Both, US and European codes and regulations, admit only approved materials for the fabrication of heavy pressure components.

All codes and regulations specify the requirements of Mn-Mo and Mn-Mo-Ni alloys quenched and tempered steel plates. Included are in general requirements for manufacture, chemical composition, heat treatment and mechanical properties. All the non-mandatory requirements which do not apply according to ASME unless specified by the customer are specified and mandatory requirements according to the German KTA regulations (and some of them are mandatory also according to the French RCC-M regulations) as e.g. vacuum treatment, restricted concentration of residual elements, extra chemical analysis, mechanical testing, ultrasonic and magnetic particle examination, Charpy V-notch impact and the drop weight tests for the measurement of the nil-ductility transition temperature.

Table I gives typical composition of US and European steels in use for reactor pressure vessels.

Chemical composition as determined by ladle analysis (Composition in %) shall comply with the requirements in table I.

The ASME specifications allow quite a wide range of levels of the major elements and within these ranges the steel-maker and pressure vessel manufacturer must choose the narrow composition limits which will allow successful fabrication and achievement of adequate mechanical properties. Only few steel makers are able to work reproducibly within very narrow composition bands. Improved mechanical properties, reduced formation of fabrication defects and reduced in-service degradation of mechanical properties can be achieved by controlling chemical composition more closely than required by current ASME specifications. This is already common practice in European countries.

Inspection of all major impurity elements with concentrations below the maximum permissible values is of utmost importance to improve material quality.

The reduction in carbon content reduces susceptibility to HAZ cracking and contributes to the achievement of a lower transition temperature; restriction of some elements such as phosphorus, arsenic, antimony and tin to levels of tens of ppm is required to avoid temper embrittlement. It is also known that the use of steels with sulphur contents below 0.010 wt% is an important factor in obtaining good upper shelf toughness.

Neutron irradiation embrittlement has been shown to be strongly influenced by chemical composition with the level of copper being most important.

The mechanical properties of steels are investigated in order to provide data for the safety analysis of the vessel.

The mandatory mechanical tests to be performed according to the different US and European codes and regulations applied are listed in table II.

The most important difference in the number of test specimens required result from the fact that under certain conditions according to the German KTA regulations test specimens are to be removed from 6 different points of a plate, at top and bottom and offset by 120°. The ASME Code and the French regulations ask for the removal of test specimen from two points, that is from one side of the plate and offset by 180°. It should be mentioned that the large number of material tests according to the French regulations originate from the fact that they give much importance to the impact tests by Charpy V-specimen. They ask in detail for the following impact tests, in total 120:

Amongst these:

- 18 tests are performed to determine the nil-ductility transition temperature
- 39 tests are performed after simulated stress relieving heat treatment and
- 24 tests are performed from the material as delivered.

4. Hydrostatic tests

The discussion on the usefulness of hydrostatic tests is still continuing. On the one hand it is argued that the cold hydrostatic test is the most effective way of performing an integral inspection of the vessel and thus of preventing a nuclear pressure vessel with large initial defects from entering into service. On the other hand it is considered that the actual pre-service and in-service inspection practices as well as the practices and experiences with fracture mechanics methods are so far developed that experts can entirely rely on them and prevent the risk of vessel failures by overpressurization with pressures much higher than operating pressures and performed at dangerous cold conditions.

At present hydrotests are still performed at both sides of the Atlantic Ocean. But while in the US system related tests are performed, the European tests are component related. This means in detail that according to the ASME Code the test pressure of a component is dependent on the design pressure of the entire system and hydrostatic tests are generally performed at pressures not more than 1.25 times the lowest design pressure of any component within the system. In European countries the test pressures are dependent on component material (forging or cast steel) and the test medium (water or air), varying between 1.1 and about 2.0 times component design pressure.

The difference can best be demonstrated when applying the French test practice:

The hydrostatic test pressure for individual tests shall not be less than $K \times$ design pressure where $K = K_1 \times K_2$

$K_1 = 1.25$ for a component consisting of forged parts,

$K_1 = 1.5$ for a component consisting wholly or partially of cast steel parts,

K_2 being the ratio of the minimum values for tensile strength at test temperature to the design temperature.

Maximum pressure limits exist however for hydrostatic tests

K remains 1.5 when $K_1 = 1.25$ and $K_1 \times K_2 > 1.5$ and

K remains 1.8 when $K_1 = 1.5$ and $K_1 \times K_2 > 1.8$.

The German regulations specify the hydrostatic test pressure to be 1.3 times design pressure for forged parts and 1.5 times design pressure for cast steel parts. The test temperature will be defined according to brittle fracture criteria.

5. Non-destructive examination

Also in the area of non-destructive examination the ASME Code is based on the older design code for steam boilers, so that even today the only volumetric examination called for is by radiography. With greater wall thicknesses of nuclear components ultrasonic testing was introduced for the basic material, while for weld seams radiography is still employed.

In the US the non-destructive examinations are performed before and during fabrication according to ASME Section III and the in-service inspection is performed according to ASME Code Section XI requirements. The defect acceptance criteria in both Code Sections are, however, incompatible so that the pre-service inspection cannot provide a so-called "finger-print" for subsequent in-service inspections as it is required according to regulations in some European countries.

In Germany it is even required that pre-service and in-service inspections be performed by the same automatic techniques. As for in-service inspections residual radioactivity at the pressure vessel makes it desirable to use remotely operated mechanical scanning equipment, the same technique is applied in the pre-service inspection.

There are also differences in in-service inspection intervals outlined in ASME, French and German requirements.

It is certainly of importance that the intervals of in-service inspections are fixed in such a way that the growth rate of a known developing crack can be defined in order to prevent the development of an unacceptable crack.

A recent round robin exercise, the so-called PISC (Periodic Inspection of Steel Components) procedure investigated the effectiveness of different inspection procedures and methods applied in most European countries. Results showed that alternative methods (alternative to the PISC procedures which were based on the ASME XI procedure) give under certain conditions much better test results than the PISC procedure. It was then decided to perform a second round robin PISC exercise with most emphasis on the effectiveness of the applied test techniques. The objectives of this PISC II programme are:

- to evaluate the effectiveness of NDE techniques in use and being developed for the in-service inspection of reactor pressure vessel components with respect to in-service induced flaws,
- to identify techniques for acceptance tests, pre-service inspection (PSI) and in-service inspection (ISI) which could be generally accepted, and
- to bring the conclusions of the programme to the attention of the Code, Standard and Regulatory bodies concerned with ISI.

Details of the PISC II exercise are being reported at the Post Conference Seminar.

6. References

- / 1 / ASME Boiler and Pressure Vessel Code Section III Nuclear Power Plant Components, 1980 edition.
- / 2 / KTA 3201 Sicherheitstechnische Regel - Komponenten des Primärkreises von Leichtwasserreaktoren, 1981.
- / 3 / AFCEN - Règles de conception et de construction des matériels mécaniques des îlots nucléaires PWR, RCC-M, édition janvier 1981. 2ème modificatif janvier 1982.
- / 4 / "Sammlung und vergleichende Betrachtung der bestehenden Richtlinien und Vorschriften über Auslegung, Herstellung, Prüfung und Inspektion von Stahlreaktor-druckbehältern"
EUR-Studienvertrag No. 390-77-12-ECIL Dezember 1977.

Table I - Chemical Composition as determined by ladle analysis
(Composition in %)

Elements	US Requirement for ASTM 508 class 2	German Require- ment 20MnMoNi55	French Require- ment for Grade 16 MN D5
Maximum carbon	0,27 max.	0,17-0,23	0,20
Manganese	0,5-1,0	1,2-1,5	1,15-1,55
Maximum phosphorus	0,015 max. (0,012)	0,012 max.	0,012
Sulphur maximum	0,015 max.	0,012	0,010
Silicon	0,12 max.	0,15-0,3	0,10-0,30
Nickel	0,5-1,00	0,5-0,8	0,50-0,80
Chromium maximum	0,25-0,45	0,2 max.	0,30
Molybdenum prescribed min.	0,55-0,7	0,4-0,55	0,45-0,55
Maximum vanadium	0,05 max.	0,02	0,01
Maximum copper	0,15 (0,1)	0,1	0,10
Aluminium maximum		0,01-0,04	0,04
Maximum cobalt		0,03	0,03

Table II - Numbers of test specimens required under
the different codes and regulations

	ASME III (SA 508)	KTA 3201 (20MnMoNi55)	RCC-M Sec.2 (16MN D5)
Ladle Analysis	1	1	1 (+1)
Product Analysis	2	2 (+4) (C;Mn;P;S)	2
Tensile Test	8	20	6
Impact Test	24	154	120
Drop Weight Test	8	20	8
K _{IC} - Test	-	2	-
	Forging: ≤ 4540 kg ≤ 2630 mm lg.	Forging: d ≤ 2000 m ≤ 3000 mm lg.	Forging for PWR (belt line)